trollers (DACs), analog to digital controllers (ADCs), and other components, as is well known to those skilled in the art.

Other input devices 118 are included in mouse 12 and send input signals to microprocessor 110 or to host 14 when manipulated by the user. Such input devices include buttons 16 and can include additional buttons, dials, switches, scroll wheels, or other controls or mechanisms.

Power supply 120 can optionally be included in mouse 12 coupled to actuator interface 116 and/or actuator 18 to provide electrical power to the actuator or be provided as a separate component. Alternatively, power can be drawn from a power supply separate from mouse 12, or power can be received across a USB or other bus. Also, received power can be stored and regulated by mouse 12 and thus used when needed to drive actuator 18. For example, power can be stored over time in a capacitor or battery and then immediately dissipated to provide a jolt force to the button 16. A safety switch 122 can optionally be included to allow a user to deactivate actuator 18 for safety reasons. For example, the user must continually activate or close safety switch 132 during operation of mouse 12 to enable the actuator 18. If, at any time, the safety switch is deactivated (opened), power from power supply 120 is cut to actuator 18 (or the actuator is otherwise disabled) as long as the safety switch is opened. Embodiments include an optical switch, an electrostatic contact switch, a button or trigger, a hand weight safety switch, etc.

FIG. 5 is a diagram of display screen 26 of host computer 14 showing a graphical user interface for use with the present invention. The force feedback mouse of the present invention can provide force sensations that make interaction with the graphical objects more compelling and more intuitive. The user typically controls a cursor 146 to select and manipulate graphical objects and information in the graphical user interface. The cursor is moved according to a position control paradigm, where the position of the cursor corresponds to a position of the mouse in its planar workspace. Force sensations can be output using actuator 18 based on signals output from the local microprocessor or host computer.

For example, a jolt sensation can be output, which is a single impulse of force that quickly rises to the desired magnitude and then is turned off or quickly decays back to zero or small magnitude. A vibration can also be output, which is a time-varying force that is typically periodic, e.g. a force vs. time waveform that is shaped like a sine wave, triangle wave, or sawtooth wave. The vibration causes the button 16a to oscillate back and forth on the Z axis, and can be output by the microprocessor to simulate a particular effect that is occurring in a host application. A constant force can also be output on the user object. This is a force having a constant magnitude that is output for a specified period of time or until a condition occurs, such as a user-controlled cursor or graphical object being moved to a predefined location in a displayed graphical environment.

Another type of force sensation that can be output by actuator 18 is a texture force. This type of force is similar to a repeating jolt force, but depends on the position of the mouse in its planar workspace (or on the position of the cursor in the graphical user interface). Thus, texture bumps are output depending on whether the cursor has moved over the location of a bump in a graphical object. This type of force is spatially-dependent, i.e. a force is output depending on the sensed position of the mouse as it moves over a designated textured area; when the mouse is positioned

between "bumps" of the texture, no force is output, and when the mouse moves over a bump, a force is output. Other spatial force sensations can also be output. In addition, any of the described force sensations herein can be output by actuator 18 simultaneously or otherwise combined as desired.

Windows 150 and 152 display information from application programs running on the host computer 14. Force sensations can output on the button 16a based on interaction between cursor 146 and a window. For example, a z-axis "bump" or jolt can be output on the button 16a when the cursor is moved over a border of a window 150 or 152 to signal the user of the location of the cursor. When the cursor 146 is moved within the window's borders, a texture force sensation can be output. The texture can be a series of bumps that are spatially arranged within the area of the window in a predefined pattern; when the cursor moves over a designated bump area, a bump force is output on the button 16a. A jolt or bump force can be output when the cursor is moved over a selectable object, such as a link 154 in a displayed web page or an icon 156. A vibration can also be output to signify a graphical object which the cursor is currently positioned over. Furthermore, features of a document displaying in window 150 or 152 can also be associated with force sensations. For example, a jolt can be output on button 16a when a page break in a document is scrolled past a particular area of the window. Page breaks or line breaks in a document can similarly be associated with force sensations such as jolts.

Menu 154 can be selected by the user after a menu heading or button such as start button 156 is selected. The individual menu items 156 in the menu can be associated with forces. For example, bumps can be output when the cursor is moved over the border between menu items 156. Icons 160 and 161 can be associated with textures, jolts, and vibrations similarly to the windows described above. Drawing or CAD programs also have many features which can be associated with force sensations, such as displayed (or invisible) grid lines or dots, control points of a drawn object, etc.

Another type of force sensation is a spring force provided by the actuator 18 rather than (or in addition to) force provided by a mechanical spring. The magnitude of this force sensation is dependent on the distance of the button from the origin of the spring. Thus, a more sophisticated sensor 113 is preferably used to sense the position of the button 16a in its degree of freedom. If the origin of the spring is at the rest position of the button, then the further the button is moved from the rest position, the greater the spring force opposing that motion. This force sensation can be associated with graphical objects and can be differentiated using magnitude. For example, when the user positions the cursor 146 over an icon 156 and presses the button, a light spring force resists the pressed motion of the button. When the user positions the cursor 146 over a different graphical object, such as icon 160, a heavy spring force is output having a greater magnitude than the spring force for icon 156.

Similar to the spring force, a "well" sensation can be output. When the cursor is positioned over a selectable graphical object, the button 16a can be mode to dip or move downward a slight amount as if the cursor were then at a lower elevation. This sensation can be used to indicate the status of a graphical object or to differentiate different graphical objects having different well "depths". In other embodiments having a button with a relatively large range of movement, a simulated 3-D surface can be simulated, where